APPENDIX G

METHODS FOR DETERMINING ENVIRONMENTAL RADIATION DOSE

Most of the radionuclides released to the atmosphere and to the Savannah River from Savannah River Plant operations are not detectable by routine environmental monitoring due to the very low levels of released material. Therefore, mathematical models were developed to predict the fate of the radionuclides in the environment and the subsequent dose commitment to offplant population groups. A number of pathways (or vectors) have been identified by which radionuclides are introduced into or may affect the human body. These include air, drinking water, transfer in food crops, external radiation from deposited radioactivity, etc., and are included in the model. These same vectors are analyzed in the routine environmental monitoring program and verify that the mathematical models do not underestimate the population dose commitment. Because population dose cannot be measured (again because of the very low levels released, but with the exception of tritium which is released in quantities sufficient to measure the dose), the dose estimate calculated by the mathematical model cannot be attributed to have a high degree of precision; however, it is estimated that actual dose would not be less than one-half nor more than twice the dose figures given.

DOSE COMMITMENT

As used in this appendix, "dose commitment" means radiation dose equivalent[1] that will be received in a 70-year lifetime by population groups as a result of a given release of radioactive materials to the environment. This includes commitments from:

- External dose from radioactive materials in the atmosphere and on the earth's surface.
- Internal dose from radioactive materials entering the human body.

Vectors that do not result in significant doses to the population groups discussed in this statement are not included in the mathematical model. For example, global recycling of tritium, carbon-14 and krypton-85, after mixing with the earth's atmosphere, is not considered; the subsequent dose to the population groups discussed in this statement is significantly less than the initial dose from the release of these nuclides.

POPULATION

It is estimated that the population groups considered in this report have increased about 10% during the period of SRP operation. However, all dose commitment calculations in this report assume a constant population size, based on the 1970 census. This was done to simplify population dose calculations and is a reasonable approach considering the degree of precision of population dose calculations. The population doses calculated for the years prior to 1970 will be conservative (overestimated) due to the population increase since that time. The population distribution is shown in Figure G-1.

DOSE VECTOR MODELS

For members of the public to be exposed to radioactivity released from SRP, the radioactive material must be transported to the recipient population groups. The two basic transport media for SRP releases are air and water. From these arise numerous exposure vectors. Fourteen vectors were selected for atmospheric releases (Figure G-2) and sixteen vectors for liquid releases (Figure G-3), based on a study of demography, meteorology, topography, and agricultural practices. The numbered lines on the model diagrams are for purposes of identification and compilation of data and will be described in the sections which discuss each model.

ATMOSPHERIC RELEASES

The calculational technique used for determining atmospheric dilution or dispersion of radioactive gases, vapors, and particles is described in Appendix F. These procedures provide the following data for each radionuclide released to the atmosphere:

1. Integral external gamma dose from passage of gamma-emitting radionuclides in the atmosphere. (The passage of radioactive material may either by overhead, i.e., a plume that has not reached ground intercept, or at ground level, where it submerges a recipient in a radioactive cloud.) Uncollided gamma photon energy flux is corrected for buildup for the two conditions of passage. In addition, provision is made for calculating gamma dose from radioactive daughter nuclides born in transit. Calculations are made for each radionuclide in sixteen 22.5° azimuthal sectors and twenty 5-km radial increments from the geographic center of the Savannah River Plant, a total of 320 locations (Figure G-1).

2. Integral air concentrations [(Ci-sec)/m^3] of each radionuclide at the 320 locations described in 1.

3. Integral areal deposition [(Ci-sec)/m^3] of each radionuclide at the 320 locations described in 1. This is not applicable to noble gases.

For each radionuclide released, a dose conversion factor was calculated for dose vectors shown in Figure G-2. These factors are in terms of integral lifetime dose (70 years) per annual average air concentration [rem/(Ci-yr/m^3)] and areal deposition [rem/(Ci-yr/m^2)]. In the computer program for calculating dose, the dose conversion factors are divided by 3.15×10^7 (sec/yr) to be compatible with units of integral air concentration [(Ci-sec)/m^3] and integral deposition (Ci)/m^2, the output forms of the atmospheric dispersion calculations. The dose conversion factor, so modified, is used as a multiplier with output from the dispersion program. The lifetime dose commitment from each radionuclide released can be calculated for an individual at each of 320 areal segments (20 radial increments, 16 azimuthal sectors) within 100 km from the geographical center of the plant. This represents a land area in a circle extending 50 miles from the plant perimeter. Individual dose data for each areal segment is multiplied by the number of people in each segment, and the resultant doses from each of the 320 radial increments are summed to obtain total man-rem dose commitment. Provision is made for calculating whole body dose, skin dose, critical organ dose, and identification of the critical organ.

External gamma radiation dose from airborne activity (vector 01, Figure G-2) is calculated by use of dose conversion factors that are a function of the gamma energy being considered. Provisions are made in the MAN-REM program to calculate external gamma cloud dose from library data obtained from processing the meteorological data for various gamma energies.

Figure G-2 shows diagrammatically the vectors selected for use in the SRP atmospheric release model. A description of each follows:

01 *External Gamma Cloud or Plume.* This represents penetrating whole body gamma dose from submersion in an atmosphere containing radioactive materials or from passage overhead of a plume containing radioactive materials.

02 *External Beta Cloud.* This represents beta skin dose from submersion in an atmosphere containing radioactive materials. Because of the short range of beta particles in air, beta skin dose is not calculated for overhead passage of a plume where the receptor is not submerged in the plume.

03 *External Gamma Deposition.* This represents penetrating whole body gamma dose at 1 meter above ground level from radioactive materials deposited on the surface of the earth from passage of a cloud or plume containing radioactive materials. At each of the 320 geographical locations for which this is calculated, the surface deposition is treated as an infinite plane source uniformly contaminated. Uncollided gamma photon energy flux is corrected for buildup.

04 *External Beta Deposition.* This represents beta skin dose from radioactive materials deposited on the surface of the earth. Dose calculations are based on a finite plane disk source, uniformly contaminated; and the radius of this disk depends on the range of the energy of the beta particles for each radionuclide.

The vectors for external radiation, 01 through 04, do not take into account variables which attenuate the dose, such as shielding afforded by occupancy in buildings, reduction in beta dose by clothing worn, or roughness factors for the surface on which the radioactive materials are deposited. The beta skin dose is calculated at a skin depth of 0.07 cm (7 mg/cm^2) and thus overestimates exposure of the lens of the eye. The integrated beta depth dose to the testes was calculated, but was so small (less than 2% of the skin dose for the highest energy beta considered) that it was not included as an organ dose vector.

05 *Internal Dose - Critical Organ - Inhalation.* This represents the internal dose to the critical organ for each radionuclide that is taken into the body by inhalation. Dose is calculated as lifetime (70 years) commitment from an integral uptake of radioactive material.

06 *Internal Dose - Whole Body - Inhalation.* This is the same as vector 05 except it treats the whole body as the critical organ. Calculations use the simplifying assumption that the radionuclide is distributed uniformly throughout the human body. In those cases where distribution is not uniform or is unknown, the dose so calculated is conservatime (overestimates the body dose). This method is also used in other vectors for internal dose where whole body is treated as the critical organ, i.e., vectors 08, 10, 12, and 14.

07 *Internal Dose - Critical Organ - Deposition - Domestic Water Supply.* This represents integral dose to the critical organ received from consumption of surface water supplies, i.e., lakes, ponds, and streams, which have been contaminated by deposition of radioactive materials from airborne radioactivity.

This is not an important vector in the areas contiguous to the Savannah River Plant because most domestic water is obtained from deep wells or from the Savannah River upstream from SRP. The Savannah River upstream receives its water from a vast water shed extending to the Appalachian Mountain chain to the west, an area so distant that aerial deposition from SRP releases can be ignored.

08 *Internal Dose - Whole Body - Deposition - Domestic Water Supply.* This is the same as vector 07 except it treats the whole body as the critical organ.

09 *Internal Dose - Critical Organ - Consumption of Vegetation Containing Radioactive Materials.* This represents integral dose to the critical organ received from consumption of vegetative farm crops which contain radioactive materials as a result of foliar deposition and uptake from the soil. This vector contributes a very small portion of the population exposure because of the nature and quantity of releases of radioactive materials from SRP.

10 *Internal Dose - Whole Body - Consumption of Vegetation Containing Radioactive Materials.* This is the same as vector 09 except it treats the whole body as the critical organ.

11 *Internal Dose - Critical Organ - Consumption of Meat Products Containing Radioactive Materials.* This represents integral dose to the critical organ from consumption of meat products from herbivorous animals which have been fed on vegetative crops containing radioactive materials of SRP origin. This vector contributes a very small portion of the population exposure because of limited production of meat products in the near vicinity of SRP and because of the nature and quantity of radioactive materials released.

12 *Internal Dose - Whole Body - Consumption of Meat Products Containing Radioactive Materials.* This is the same as vector 11 except it treats the whole body as the critical organ.

13 *Internal Dose - Critical Organ - Milk Consumption.* This represents integral dose to the critical organ received from consumption of locally produced milk. Exposure is via the forage-cow-milk pathway. This is an important vector for three of the radionuclides released at SRP, tritium, iodine-129, and iodine-131.

14 *Internal Dose - Whole Body - Milk Consumption.* This is the same as vector 13 except it treats the whole body as the critical organ.

For vectors 07 through 14, population dose calculations depend largely on environmental monitoring data, i.e., analysis of foods available to the public. The dose model can be used to calculate specific individual dose commitments to persons who produce and consume their own food at any of the 320 geographical locations included in the computational program. It is for this group, i.e., small farmers, that the data for *individual* dose commitment apply.

All possible dose vectors have not been included in the dose model for atmospheric releases, but no important vectors have been omitted. Table G-1 presents a computer-calculated summary of man-rem doses for all radionuclides released to the atmosphere in 1975. The summary shows cumulative dose by radial increment from 20 km (plant perimeter) to 100 km (50 miles from the plant perimeter). Table G-2 shows dose contributed by individual radionucludes to population dose, to individuals, and to individual organs. An isopleth of whole body dose to the individual during 1975 from atmospheric releases is shown in Figure G-4.

RELEASES TO LIQUID EFFLUENTS

Radioactive materials enter the Savannah River or have the potential for future entry by four mechanisms resulting from current and past waste management practices. These mechanisms are:

1. *Direct discharge to effluent streams.* Low concentrations of radioactive materials in large volumes of water are discharged to surface streams flowing to the river. No practical method currently exists for removing these radioactive materials because they are generally aqueous flows that have already been decontaminated to as low a level as practical at the point of release. Tritium (oxide) cannot be removed from the effluents with existing technology. All of the radionuclides released in this manner are below the Concentration Guides (ERDAM 0524) at the point of departure from the SRP site and, after dilution in the Savannah River, are less than 1% of the Concentration Guides for uncontrolled areas.

2. *Discharge to and retention in effluent streams.* Some radioactive materials discharged to effluent streams do not flow directly to the Savannah River because of retention in the stream and stream components by complex chemical and biological phenomena. Most notable is cesium-137, which is partially retained by stream sediments, vegetation, and organic detritus. At SRP, less than 20% of the cesium-137 discharged reaches the Savannah River during the year of discharge. The remainder desorbs over tens of years. The cesium that is not lost through radioactive decay will contribute to discharges to the river in future years.

3. *Discharge to seepage basins.* Some low-level liquid wastes are discharged to earthen seepage basins to prevent surges of radioactivity in plant streams and to allow short-lived nuclides to decay. The water in these basins moves downward to the water table and then flows laterally with the ground water to outcrop areas near or along effluent streams. The movement of radioactive materials depends on the element, its chemical form, and its ion exchange characteristics in the soil. Tritium (oxide) moves at the same rate as the seepage and ground water. All other elements experience travel delays resulting from reduction in velocity and/or immobilization by ion exchange phenomena in the soil. Delays in transport to surface streams reduce the amount of radioactivity reaching the aquatic environment by radioactive decay. Currently, only tritium and strontium are reaching surface streams. However, other very long-lived radionuclides may eventually enter the streams and contribute to future dose commitment.

4. *Burial of solid wastes.* Solid waste, containing radioactive contamination, is buried in unlined earthen trenches above the water table. In 20 years of use of burial trenches, very little radioactivity other than tritium has been detected in the ground water. Some of the moderately long-lived radionuclides such as ^{90}Sr may reach the water table, but should decay to background levels within 100 ft of the point of entry into the ground water. The inventory of tritium in the ground water is 5×10^4 Ci, and the projected population dose after migration to the nearest stream is less than 1 man-rem. It is estimated from measurements that the fastest moving radionuclidic compound, tritium oxide, would take approximately 70 years to reach a stream, once it has reached the ground water beneath the burial trenches. 98% of the long-lived transuranium elements in solid waste are buried in concrete containers for future retrieval and should not contribute to future population dose commitment.

The four mechanisms of release cannot be mathematically modeled with a satisfactory degree of precision because of many unknown parameters and variables in ground water and surface water transport of radionuclidic compounds. An aqueous transport model is being developed with the intent to be combined with a dose vector model (Figure G-3); these models will be used as a predictive tool for waste management programs.

As in the atmospheric release model, dose factors were calculated for each radionuclide for each important vector in terms of integral dose commitment per integral radionuclide concentration {rem/[(Ci-yr)/m^3]}. When used as multipliers for concentrations of radionuclides in the various aqueous vectors, the dose

commitment to critical population groups can be calculated for each radionuclide. Sixteen vectors are shown in the liquid release model. A description of these vectors follows:

21 *Internal Dose - Critical Organ - Untreated River Water Consumption.* This represents the integral internal dose to the critical organ for each radionuclide that is taken into the body by ingestion of untreated river water. No such population is known to exist and is included primarily to represent a maximum dose possible from river water consumption.

22 *Internal Dose - Whole Body - Untreated River Water Consumption.* This is the same as vector 21 except it treats the whole body as the critical organ.

23 *Internal Dose - Critical Organ - Treated River Water Consumption.* This is the same as vector 21 except that it applies to customers of the two water treatment plants downstream from SRP, i.e., the Beaufort-Jasper, S.C. Water Authority and the Cherokee Hill Water Treatment Plant, Port Wentworth, Georgia. See Tables G-3 and G-4 for a description of utilization of water from these plants. At present, these plants are the only significant dose vector for liquid releases of radioactive materials.

24 *Internal Dose - Whole Body - Treated River Water Consumption.* This is the same as vector 23 except the whole body is treated as the critical organ.

25 *Internal Dose - Critical Organ - Fish Consumption.* This represents integral critical organ dose from consumption of Savannah River fish. Bioaccumulation of radionuclides in fish flesh is taken into account. There is very little commercial fishing on the Savannah River. Thus, this vector is used only to calculate doses to individuals and is not applicable to any discrete population group. This vector is included in the hypothetical dose calculation to individuals but not in the man-rem calculations.

26 *Internal Dose - Whole Body - Fish Consumption.* This is the same as vector 25 except the whole body is treated as the critical organ.

27 *Internal Dose - Critical Organ - Consumption of Irrigated Food.* There is no known use of Savannah River water for irrigation purposes. This vector is included only for consideration of potential future utilization of river water.

28 *Internal Dose - Whole Body - Consumption of Irrigated Food.* This is the same as vector 27 except the whole body is treated as the critical organ.

29 *Internal Dose - Critical Organ - Consumption of Livestock Watered with River Water.* This represents critical organ dose from consumption of meat products from animals watered with river water. This vector is relatively unimportant because there are no known locations where river water is pumped for watering purposes, and the river is virtually inaccessible to livestock at most downstream locations because of heavy, swamplike growth and steep river banks. Farmers in this region generally depend on wells and farm ponds as a source of water for livestock.

30 *Internal Dose - Whole Body - Consumption of Livestock Watered with River Water.* This is the same as vector 29 except the whole body is treated as the critical organ.

31 *Internal Dose - Critical Organ - Consumption of Vegetative Crops Grown in Dredge Sediments.* The Savannah River is dredged periodically to maintain a navigable channel between Savannah, Georgia, and Augusta, Georgia. Most of the dredging occurs in the Savannah Harbor where heavy silting occurs when fresh river water mixes with tidal salt water intrusion. Spoil areas for the sediments have been placed in two locations, and some farming is currently done on the spoil area containing sediments up through 1957. These sediments contain ^{137}Cs concentrations ranging from 0.1 to 2.0 pCi/g. Food crops grown in the sediments (corn, cucumbers, and soy beans) all contain less than 0.6 pCi/g of ^{137}Cs[11] (sensitivity of analysis) and thus, are not a significant contribution to population dose.

32 *Internal Dose - Whole Body - Consumption of Vegetative Crops Grown in Dredge Sediments.* This is the same as vector 31 except the whole body is treated as the critical organ.

33 *External Gamma Dose - Whole Body and External Beta Dose - Skin.*
34 These vectors are to account for direct radiation received
35 from submersion in river water (swimming), living or working
36 at water surface, and living or working near exposed river
37 bank and dredge sediments. All of these vectors apply to individuals rather than population groups.

During 1975, the only liquid release vectors affecting large population groups were 23 and 24, treated water consumption. The man-rem dose estimates for these vectors for customers of the Beaufort-Jasper, S.C., Water Authority and for the Cherokee Hill Water Treatment Plant, Port Wentworth, Georgia, were calculated

based on calculated concentrations of radionuclides in treated water in 1975.

DOSE CALCULATIONAL TECHNIQUES

Techniques for calculating dose were patterned after methods used by the ICRP.[3,4] Standard man data were used except where infants were critical members of the population. Equations were derived to provide a factor for converting integral concentrations of radionuclides in various media to lifetime dose commitment via the various vectors. Dose factors for atmospheric vectors are shown in Table G-5 and in Table G-6 for liquid release vectors. The method for calculating these factors is illustrated in this section by showing the derivation of some of the equations for atmospheric vectors.

Internal Dose: The dose rate to an organ or to the body is a function of the amount of radioactive material present. The amount q of radioactive material in the body at any time t can be expressed as

$$q_t = q_o e^{-\lambda t} \qquad \text{(G-1)}$$

where

q_t = amount of radioactive material in the body at time t

q_o = initial amount of radioactive material (initial uptake)

λ = effective decay constant for the radionuclide, $days^{-1}$

The integral amount of radioactive material in an organ or the body can be obtained by integrating equation G-1

$$Q = q_o \int_o^T e^{-\lambda t}\, dt = q_o \left(\frac{1 - e^{-\lambda T}}{\lambda} \right) \qquad \text{(G-2)}$$

For the inhalation route of uptake, the 70-year dose commitment can be calculated, using Equation G-2.

$$\text{Dose}_{70} = \frac{(365)(2\times10^{7})(C)(f)(3.7\times10^{4})(\varepsilon)(1.6\times10^{-6})(8.64\times10^{4})}{(100)(m)(\lambda)} \times$$

$$(1 - e^{-2.555\times10^{4}\lambda}) = \frac{3.7\times10^{11} fC\varepsilon}{m\lambda} (1 - e^{-2.555\times10^{4}\lambda}) \qquad \text{(G-3)}$$

where

365 = days/yr

2×10^{7} = inhalation rate, cc/day

C = concentration of radionuclide in air, $\mu Ci/cc$ (or Ci/m^3)

f = fraction of radionuclide inhaled that reaches organ of interest

3.7×10^{4} = dis/(sec-μCi)

ε = effective energy in organ of interest, MeV

1.6×10^{-6} = ergs/MeV

8.64×10^{4} = sec/day

2.555×10^{4} = days in 70 years

100 = ergs/(g-rad)

m = mass of organ of interest, g

λ = effective decay constant, $days^{-1}$

To obtain a dose commitment conversion factor, Equation G-3 is rearranged:

$$D_c = \frac{Dose_{70}}{C} = \frac{3.7 \times 10^{11} f \varepsilon}{m\lambda} \left(1 - e^{-2.555 \times 10^{4} \lambda}\right) \qquad \text{(G-4)}$$

Equation G-4 applies to any organ except the G.I. tract. The dose conversion factor, for any mode of uptake, can be generalized by:

$$D_c = \frac{Kf\varepsilon}{m\lambda} \left(1 - e^{-2.555 \times 10^{4} \lambda}\right) \qquad \text{(G-5)}$$

where

K = a constant related to rate of intake.

Some values of K used in derivation of dose conversion factors are listed in Table G-7.

Dose calculations for the G.I. tract are treated separately from other body organs because the various portions of this system are subject to a relatively constant elimination rate and are exposed to radiation only during passage of the contents. From ICRP,[3] dose conversion factors for an integral intake were derived.

$$D_c = \frac{\text{Dose}}{C} = \frac{fI(3.7\times10^4)(8.64\times10^4)(365)(1.6\times10^{-6})(\varepsilon)(d\tau)e^{-\lambda_o t}}{(2)(100)(m)(d\tau/\tau)}$$

$$= \frac{9.3\times10^3 fI\varepsilon\tau\ e^{-\lambda_o t}}{m} \qquad \text{(G-6)}$$

where

f = fraction of material reaching G.I. tract

I = intake rate, ml or g/day for liquids and foods and cc/day for inhalation

ε = effective energy in critical section of G.I. tract, Mev

m = mass of contents of portion of G.I. tract considered, g

τ = residence time in portion of G.I. tract involved, days

λ_o = radioactive decay constant, days^{-1}

t = time for ingested material to reach portion of G.I. tract considered; $e^{-\lambda_o t} \cong 1$ for half-lives greater than 4 days

Equation G-6 can be simplified to account for different modes of intake, i.e.,

$$D_c = \frac{Kf\ \varepsilon\tau\ e^{-\lambda_o t}}{m} \qquad \text{(G-7)}$$

where

K = a constant depending on mode of intake

Values for K for the G.I. tract are given in Table G-8.

Values for constants for various portions of the G.I. tract are listed in Table G-9.

External gamma dose from submersion is calculated in the meteorological program which takes into account dose from submersion and/or dose received by passage overhead of a plume of radioactive gases (before ground intercept). Skin dose is equal to whole body dose when the radioactive material approaches the receptor to nearer than 10 m because irradiation is then from gamma only. For submersion, skin dose increases significantly because of the contribution of beta radiation. In the case of

submersion, the receptor is assumed to be at the center of a hemispheric cloud having a radius equal to the range of beta particles. This method is the generally accepted practice.[4,5] The dose factor for beta irradiation by submersion in air can be derived as follows.

To obtain total skin dose, the gamma dose (calculated in other parts of the program) is added to the beta dose obtained from Equation G-8.

Radioactive materials deposited from the atmosphere on dairy pastures enter the grass-cow-milk vector. For two of the more important radionuclides released at SRP, tritium and iodine-131, reasonably consistent relationships have been observed between the concentration of these nuclides in air and their concentration in milk. The relationship can be expressed as follows:

$$C_m = (CF)C_A \qquad \text{(G-9)}$$

where

C_m = concentration in milk, Ci/ℓ

CF = concentration factor

C_A = concentration in air, μCi-sec/cc (or Ci-sec/m^3)

The value of CF for tritium is 30 and for iodine-131 is 400 for chronic releases encompassing a wide range of meteorological conditions.

$$D_c = \frac{\text{Dose}}{C} = \frac{\varepsilon(1.6\times10^{-6})(3.7\times10^{4})(8.64\times10^{4})(365)(1.13)}{(1.293\times10^{-3})(100)(2)} \qquad \text{(G-8)}$$

$$= 8.16 \times 10^{6}\varepsilon$$

where

1.13 = P_a/P_t = stopping power of air relative to tissue

1.293×10^{-3} = density of air (STP), g/cc

2 = correction for cloud being hemispheric

The atmospheric dispersion program assumes a deposition velocity of 1 cm/sec for both of these nuclides. From this, the following relationship is obtained:

$$C_A = 100\ C_d \tag{G-10}$$

where

C_d = areal deposition, Ci/m^2

Substituting in Equation G-9

$$C_m = 100(CF)C_d \tag{G-11}$$

Equation G-11 can be used in calculating the dose from ^{131}I and ^{3}H by the grass-cow-milk vector as follows:

$$\text{Dose} = \frac{(365)(1)[100(CF)C_d](3.7\text{x}10^{10})(\varepsilon)(8.64\text{x}10^{4})(1.6\text{x}10^{-6})(f)}{(100)(m)(\lambda)}$$

$$= \frac{1.9\text{x}10^{12}(CF)C_d\varepsilon f}{m\lambda} \tag{G-12}$$

where

1 = milk intake, 1 ℓ/day

$100(CF)C_d$ = concentration of nuclide in milk, Ci/ℓ (from Equation G-11)

$3.7\text{x}10^{10}$ = dis/(sec-Ci)

Equation G-12 can be rearranged to obtain a dose conversion factor as follows:

$$D_c = \frac{\text{Dose}}{C_d} = \frac{1.9\text{x}10^{12}(CF)\varepsilon f}{m\lambda} \tag{G-13}$$

For the special cases of tritium and iodine-131, Equation G-13 becomes:

$$D_c(^{3}H) = \frac{5.7\text{x}10^{13}\varepsilon f}{m\lambda} \tag{G-14}$$

and

$$D_c(^{131}I) = \frac{7.6\text{x}10^{14}\varepsilon f}{m\lambda} \tag{G-15}$$

The grass-cow-milk vector for radionuclides released in particulate form was adopted from a method developed at LLL,[6] i.e.,

$$\text{Dose} = \frac{(365)(I)(C_d)(f_m)(f_w)(\varepsilon)(UAF)(3.7\times10^{10})(1.6\times10^{-6})(8.64\times10^{4})}{(100)(L_p)(m)(\lambda_v)(\lambda_e)} \qquad \text{(G-16)}$$

$$= \frac{1.9\times10^{10}(1)(C_d)(f_m)(f_w)(\varepsilon)(UAF)}{(L_p)(m)\lambda_v\lambda_e}$$

where

1 = milk intake, ℓ/day

C_d = integral areal deposition on forage, Ci/m^2

f_m = fraction of radionuclide ingested by cow appearing in milk

f_w = fraction of radionuclide ingested by man appearing in organ

UAF = utilized area factor, m^2/day (area utilized by foraging cow)

L_p = volume of milk produced per day by cow, ℓ/day

m = mass of organ, g

λ_v = effective decay constant on forage, $days^{-1}$

λ_e = effective decay constant in critical organ, $days^{-1}$

By rearranging Equation G-16, the dose conversion factor is obtained:

$$D_c = \frac{\text{Dose}}{C_d} = \frac{1.9\times10^{10} f_m f_w \varepsilon UAF}{L_p m \lambda_v \lambda_e} \qquad \text{(G-17)}$$

For dairies in the Central Savannah River Area, the UAF averages about 30 m^2/day and the L_p averages 16 l/day. Cows are on forage throughout the year, but their diet is supplemented with imported corn and oats (about 50% supplement by weight in spring and summer months and 85% during fall and winter). It is assumed that the UAF remains constant throughout the year.

Using these values, Equation G-17 becomes:

$$D_c = \frac{3.6 \times 10^{10} f_m f_w \varepsilon}{m \lambda_v \lambda_e} \qquad \text{(G-18)}$$

VARIATIONS FROM THE DOSE MODEL

Dose calculations for the long-lived radionuclides carbon-14 and iodine-129 require the use of different techniques than those normally used for other radionuclides released to the environment from SRP operations. The modifications are necessary for calculating plant boundary dose to individuals and dose to the population within 100 km because transport data and dose conversion factors for these radionuclides are not available at this time to permit use of the "vector model." A conservative approach, called variously the "specific activity model" or the "equilibrium ratio model" is used. This approach assumes that carbon-14 and iodine-129 mix with their naturally occurring isotopes in the atmosphere, and that the presence of the SRP-made nuclides in man's body instantly comes into equilibrium with the ratio of SRP-made nuclide to natural nuclide abundance in the atmosphere. The bases and assumptions used for calculating dose from carbon-14 and iodine-129 are described in the following sections.

Carbon 14

Carbon-14 (half-life = 5730 years) is produced in SRP reactors by various reactions in the fuel, coolant, and core construction materials. The reactions accounting for most of ^{14}C production are:

$$^{17}O\ (n,\alpha)\ ^{14}C$$

$$^{14}N\ (n,p)\ ^{14}C$$

$$^{13}C\ (n,\gamma)\ ^{14}C$$

The (n,α) reaction with naturally occurring ^{17}O (0.039%) present in the heavy water coolant accounts for most of the ^{14}C produced at SRP. The nitrogen occurs as an impurity in the fuel, as dissolved